THE UNIVERSITY OF TEXAS BULLETIN
No. 3543: November 15, 1935

A STUDY OF GASOLINES SOLD IN TEXAS AND REVIEW OF GASOLINE SPECIFICATIONS

By

DAVID McKNIGHT, JR., M.S. in Ch.E.

Ceramic Engineer; Secretary of the Bureau of Industrial Chemistry

and

RUBEN F. PFENNIG, B.S. in Ch.E.

BUREAU OF INDUSTRIAL CHEMISTRY

E. P. Schoch, Director
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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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This work was done at the instance and under the guidance of Dr. E. P. Schoch, Director of the Bureau of Industrial Chemistry, to whom the writers wish to express their appreciation. The work of gathering the samples and examining them was done by Messrs. Ruben F. Pfennig, Rhoden P. Ricketts, and Harrold T. White, graduate students in Chemical Engineering. A portion of the work was included by Mr. Ricketts in his thesis for the Degree of Master of Science in Chemical Engineering, presented in June, 1935.

The writers wish to acknowledge the coöperation of many Austin gasoline dealers who contributed samples for examination.

PART ONE—GASOLINE SPECIFICATIONS

INTRODUCTION

Since the advent of the automobile engine many specifications have been offered to the public and emphasized as the criterions of a good gasoline. Formally, gravity was the only quality generally specified, but as it was soon found to be of little significance, other properties were investigated, and, as a result, a complicated and sometimes conflicting system of specifications has grown up. Advertising claims for various gasolines have frequently emphasized one property with disregard for the others. Thus for some time producers vied with each other in their claims for the volatility of their products. Efforts to produce more volatile fuels resulted in fuels subject to the trouble of "vapor lock," and the industry has been forced to limit volatility. Since rivalry in this quality is no longer possible, volatility is no longer stressed so strongly in advertising. A similar condition obtained with respect to the quality of "freshness." Freshness is a composite quality to which a number of factors contribute and is probably a better criterion of good gasoline than any other single claim that might be made. It is, however, difficult to demonstrate to the public and hence does not appear to have had as much advertising value as other claims. Lack of freshness shows principally in "off color," gum formation and loss of volatility.

With the increased compression ratios employed in increasing the efficiency of the automobile engine, the anti-knock properties have come into prominence. This has resulted in the so-called "race for higher octane" in the course of which gasolines of higher and higher anti-knock values have been offered to the public and the public has been led to believe that this is the most important quality to look for in motor fuel.

It was the purpose of this study to examine the various specifications in use, their relative merits and demerits, and determine the quality of the gasolines on the market in the light of these specifications. The problem is complicated by the fact that the specifications now employed result from the combined efforts of the technologists of the gasoline producers in their efforts to improve gasoline quality, and the demands of the public, educated by the

advertising efforts of the producers. These two influences are not always in harmony. Particularly is this true at present when the public has been taught to demand gasoline of anti-knock value frequently higher than required by engine design.

VOLATILITY

Wilson[1] says, "Although a large portion of the public still clings to the belief that the principal difference between different grades of gasoline is in economy or mileage, it is a fact that the differences in mileage are small as compared with the differences in the performance of the fuels and their possible injury to the engine or the fuel-induction system." Volatility is generally conceded to be a very important property of a motor fuel, but no test measures the volatility of a fuel directly under conditions prevailing in service. Wilson described efforts made to correlate the different points on the so-called Engler distillation with various operating characteristics, such as ease of starting, acceleration, etc. These efforts have been partly successful, but the correlations are not regarded as thoroughly satisfactory. Extensive work by the Bureau of Standards and others[2] lead to the deduction that the corrected 10 per cent point on the Engler distillation was the determining factor regarding the ease of starting, evaporation, and vapor lock. Vapor lock is that condition of an engine in which the temperature of the feed lines exceeds the boiling point of the gasoline to such an extent that the fuel lines become filled with vapor, preventing the engine from getting gasoline freely. This results when the gasoline is too volatile. Evaporation losses are likewise increased with increasing volatility. Hard starting results when the gasoline is not volatile enough. Hence, there is a maximum and minimum allowable 10 per cent point on the Engler distillation. Another factor involved in volatility is crank case dilution. This results when the gasoline contains too many high-boiling constituents which are not completely vaporized in the intake manifold. Birdsell[3] found that the corrected 90 per cent point is the determining criterion of this

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[1]Robert E. Wilson, S.A.E. Trans., *25*, 151 (1930).

[2]Cragoe and Eisinger, S.A.E. Trans., *22*, pt. 1 p. 1 (1927). Bridgeman, Aldrich and White, A.P.I. Proc., Sec. III, p. 4, Jan. 1930.

[3]Roger Birdsell, S.A.E. Journal, *15*, 24 (1924).

tendency. In another investigation by the Bureau of Standards[4] it was determined that the corrected 50 per cent point determined the ease of acceleration. From consideration of the above data, Wilson concluded that proper specification of the 10 per cent, 50 per cent and 90 per cent points on the Engler distillation was sufficient to insure a gasoline of satisfactory volatility.

Volatility is not a simple property inasmuch as gasoline is a complex mixture of hydrocarbons and the volatility of the mixture is the result of the combined effects of all the components. The importance of volatility is in determining the completeness with which a gasoline vaporizes. Since completeness of vaporization determines the ease of starting and acceleration as well as, to some extent, fuel economy, volatility is very important in connection with engine performance. The Reid vapor pressure[5] does not give a true indication in this respect since a gasoline may show a high vapor pressure due to the presence of very volatile hydrocarbons and still contain such an amount of less volatile components as to give unsatisfactory volatility. Since proper engine performance usually requires an evaporation of about 70 per cent of the charge in the intake manifold, it is readily seen that the Reid vapor pressure cannot be expected to give a good correlation with operating results. Attempts to correlate with points on the Engler distillation are much more rational, particularly if the boiling-point curve is corrected on the assumption that the distillation loss corresponds to the lighter hydrocarbons which are not condensed under experimental conditions. Some such correlations[(2)(3)(4)] have already been referred to.

In an attempt to distill under conditions more nearly approaching engine conditions, the Equilibrium Air Distillation was developed. Working with the method, Bridgeman and Cragoe[6] developed a method for determining the E.A.D. curve for a gasoline from the Engler distillation data. Brown[7] was not able to confirm any such simple relationship as that of Bridgeman and Cragoe, but showed some very helpful data connecting distillation characteristics with

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[4]D. B. Brooks, S.A.E. Trans., *24*, 229 (1929).

[5]A.S.T.M. Designation D 323–32T. See p. 33 of this report.

[6]Bridgeman and Cragoe, A.P.I. Proc., Jan. 31, 1928.

[7]G. G. Brown, Proc. Nat. Gas Assn., May, 1929; Refiner, June, 1930.

ease of starting. He showed how to determine the necessary distillation curve for a gasoline to permit starting under any specified conditions. Such requirements vary considerably with various factors of engine design such as radiator shutters, manifold heaters and accelerating devices.

From such information it is conceivable that specifications might be written so that gasoline furnished would give easy starting under even the most adverse conditions of engine design and atmospheric temperature. This, however, would be economically unsound, since it would exclude much material which could be satisfactorily included in fuels for engines of improved design and operating under normal weather conditions. It would likewise be impracticable due to the limitations of volatility resulting from vapor lock and evaporation loss. Hence, a balance must be obtained between opposing factors influencing volatility. It has become common practice in the industry to vary the properties of gasolines to accord with seasonal conditions and with the localities in which the gasolines are to be used. Thus a more volatile "Winter Grade" gasoline is marketed during the winter months, but the Winter Grade gasoline offered in the southern states should not be as volatile as that offered in the northern states. Thus a gasoline prepared in accordance with such specifications should give easy starting under normal weather conditions where and when purchased. In extraordinarily cold weather, however, or in engines not equipped with improvements designed to facilitate starting, it may require heavy choking and changes in carburetor setting to give richer mixtures. Likewise, a properly prepared Summer Grade gasoline should not give rise to inordinate evaporation loss or vapor lock in hot weather. Vapor lock is not as important a factor as it once was, since it has been found that the tendency can be greatly reduced by proper design of the fuel feed system.

The United States Government, in specifications for gasoline purchased by its agencies, endeavors by means of maximum 10 per cent, 50 per cent and 90 per cent points on the distillation curve to insure sufficient volatility. It then guards against excessive volatility by reserving the right to reject material (a) in those localities where the normal minimum temperature during the month of January is greater than 27° F. if the Reid vapor pressure at 100° F. exceeds

10 pounds per square inch; and (b) during the months of June, July, August and September if the vapor pressure at 100° F. exceeds 8 pounds per square inch.

MacCoull,[8] in an investigation of the effect of volatility on motor economy, obtained much valuable information on this subject. Five gasolines were prepared as follows: A commercial motor gasoline with an end point of 386° F. was steam-distilled and the following gasolines prepared:

(1) With an end point of 312°.
(2) With an end point of 352°.
(3) With an end point of 386° (the original gasoline).
(4) With an end point of 400° (by blending the heavy ends from the steam still with the original gasoline).
(5) With an end point of 432° (by blending a light kerosene fraction with the original gasoline).

These fuels were used in fourteen different cars and data obtained under varying conditions.

The first test run was as follows: The gasoline was used in cars with normal carburetor setting unchanged. The results showed that (1) the mileage appeared to be best for the gasolines with the highest end points (see Figure 1), (2) the acceleration was better

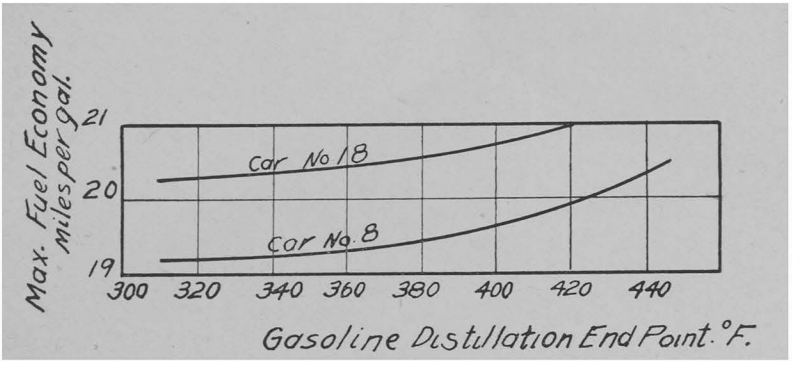

Fig. 1. Gasoline economy as related to volatility in ordinary motor car operation (MacCoull, S.A.E. Trans., *33*, 363 (1933)).

with the original fuel than with those of either higher or lower end points, and (3) the power available was approximately the same for all the gasolines used.

[8]Neil MacCoull, S.A.E. Trans., *33*, No. 5, 363 (1933).

In the second test, two of the test cars were operated at varying carburetor settings on the several fuels. The fuel economy was determined in terms of miles per gallon. The results are shown in Figure 2. The conclusion is that the more volatile the gasoline the less the economy in miles per gallon.

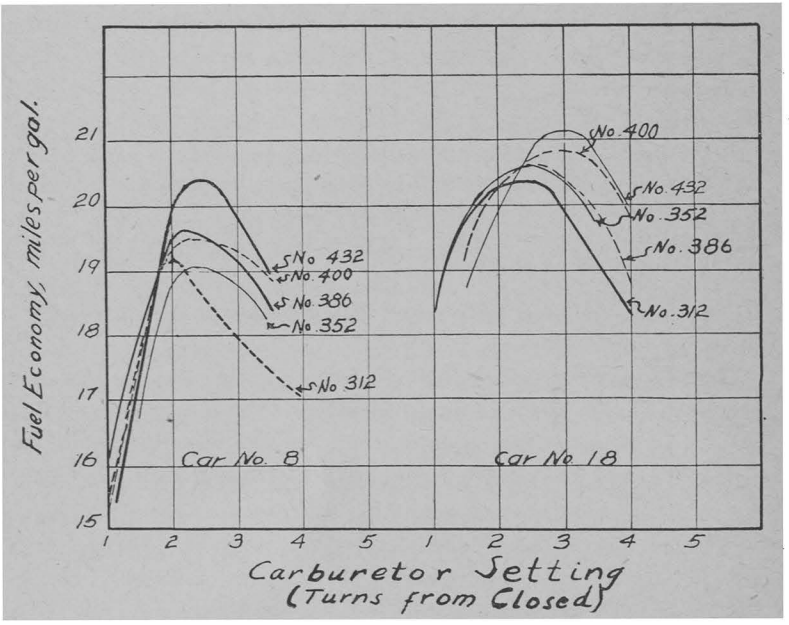

Fig. 2. Gasoline economy as related to carburetor setting for gasolines of various volatilities (MacCoull, S.A.E. Trans., *33*, 363 (1933)).

The third test run was made in a single-cylinder C.F.R. engine with variable compression head under the following four sets of conditions of mixture-temperature and compression ratio:

(1) Fixed mixture-temperature and the same arbitrarily selected compression ratio.

(2) Fixed mixture-temperature and optimum compression ratio for each fuel sample.

(3) Fixed compression ratio and optimum mixture-temperature for each fuel sample.

(4) Optimum compression ratio and optimum mixture-temperature for each sample.

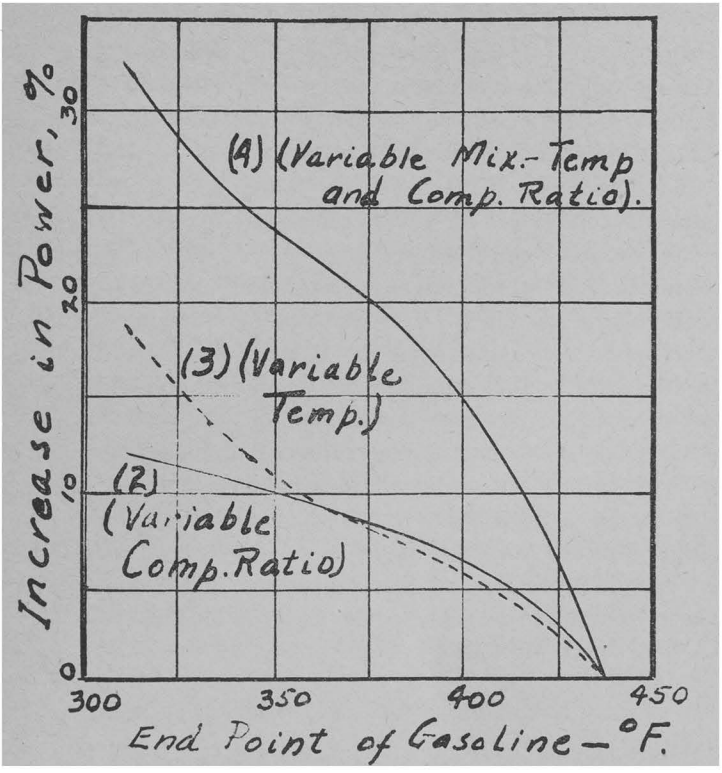

Fig. 3. Changes in power output of single cylinder engine operating with gasolines of different volatilities and under various conditions (MacCoull, S.A.E. Trans., *33*, 363 (1933)).

No conclusions of value could be made from the experiments made under the first set of conditions.

The results of the experiments made under the second set of conditions indicated that the power (strength) obtained with the most volatile fuel was about 12 per cent greater than with the least volatile one, and the fuel consumption, by weight, was about 6 per cent less for the most volatile fuel than for the volatile one.

The experiments made under the third set of conditions showed the following results: There was an increase of 18 per cent in power (strength) resulting from lowering the mixture temperature over a range of 100° F. due to the denser charge taken into the manifold. Through a modification of this step, the compression

ratio was varied on the lighter gasoline in order to determine the amount of compression ratio increase that the resulting lowering in the manifold temperature would allow. It was found that a decrease of 100° F. allowed an increase of 0.65 in the compression ratio, or a decrease in anti-knock requirement of 10 octane numbers.

The experiments made under the fourth set of conditions, i.e., optimum conditions for both compression ratio and mixture-temperature, evidently allowed advantage to be taken both of the anti-knock and of the mixture-temperature characteristics of the more volatile gasolines. This resulted in obtaining 30 per cent more power (strength) from the lightest than from the heaviest gasoline tested. This suggested the possibility of building engines with less weight per horsepower than the engines now built for ordinary gasolines, but it was realized that such possibilities are restricted by the availability of such lighter gasolines.

Summarizing MacCoull's results, the conclusion is that even with optimum gas-air mixtures, the more volatile a gasoline the less the economy in mileage, and that the more volatile gasolines yield greater power output only when used in engines designed particularly for these fuels.

KNOCK RATING

With increased compression ratios the anti-knock value of a gasoline has become virtually as important as its volatility. Knocking not only sounds unpleasant, but it results in loss of power and may actually result in damage to the engine.

Attempts have been made to correlate the anti-knock qualities of a gasoline with its chemical composition by means of the "aniline point" and by boiling-point-gravity curves. However, no satisfactory general relationship has been found. It has been found necessary to test the detonating characteristics directly. Since it appeared best to express the anti-knock quality as compared with that of a fuel of known properties, some standard, constant, non-detonating fuel was necessary. Benzol, which is a chemical compound having a very slight tendency to knock, was the first standard used generally. The "Benzol Equivalent" or "Aromatic Equivalent" was defined as the per cent by volume of benzol in a mixture of benzol with a standard straight-run paraffin-base gasoline, which mixture

had the same knocking tendency as the sample tested. Various forms of apparatus have been used to test the tendency of fuels to knock and to compare these tendencies with those of the standard fuels. The benzol equivalent, as described by Cross[9] was measured in a one-cylinder engine equipped with a head by which the compression ratio could be varied from 3:1 to 9:1. The engine was operated at constant load and speed, with constant intake and exhaust temperatures, fuel-air mixture, rate of feed and spark advance. The only variable thus was the compression ratio, and the observation was made by varying this until the first audible knock was detected.

Various modifications have since been made in attempts to improve the accuracy of the knock rate determination. The standard straight-run paraffin-base gasoline used in the determination of the benzol equivalent was not a definite chemical substance and hence was difficult to standardize. It has been replaced as an ultimate standard by normal heptane, which is a strong knock-producing hydrocarbon and can be obtained in a pure state, and hence any sample of normal heptane will always give the same knock tendency. It has also been found that as an anti-knock standard, the hydrocarbon iso-octane gives better results in conjunction with normal heptane than does benzol, and hence the anti-knock value has come to be defined in terms of "Octane Number" instead of "Benzol Equivalent." The octane number of a gasoline is defined as the per cent by volume of iso-octane in a mixture of iso-octane with normal heptane which mixture has the same knocking tendency as the gasoline in question. In routine determinations of octane number, secondary standards are used because of the fact that the pure hydrocarbons are too expensive to be used in large quantities. These secondary standards are known as "standard reference fuels." There are two standard reference fuels employed, designated as "A" and "C," both of them being carefully stabilized gasolines, "A" being of low and "C" of high anti-knock value. These reference fuels are carefully standardized against the basic standard pure hydrocarbons, so that results obtained by comparison of mixtures of these fuels can be expressed in terms of "Octane Number."

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[9]Roy Cross, "Handbook of Petroleum, Asphalt and Natural Gas." Bulletin No. 25, Kansas City Testing Laboratory, 1931.

It should be mentioned that the anti-knock value of a gasoline is sometimes expressed as "Ethyl Equivalent." This is defined as the number of cubic centimeters of Ethyl Fluid (the essential constituent of which is tetraethyl lead) which must be added to one gallon of the gasoline to raise the anti-knock value to some predetermined standard. The ethyl equivalent is of interest to the refiner who intends to add Ethyl Fluid to his product, but is not of general interest to the public. It is not directly related to octane number, since different gasolines require different amounts of tetraethyl lead for equal changes in octane number. This is commonly expressed in the industry by saying that they differ in "susceptibility to lead."

The method of comparing gasolines with the standard fuels has been modified in many respects since the time when the engine described by Cross was used. The detection of the "first audible knock" was found to be very difficult, and the accuracy obtainable by measuring the compression at which the first audible knock occurred was very low. The "bouncing pin" was devised to detect and measure the intensity of knock, thus eliminating the personal factor in the detection of an audible knock. The various engines employed and tried out in the past have finally resulted in the motor which has been approved jointly by the American Society for Testing Materials and the Coöperative Fuels Research Committee, the latter being composed of members from the American Petroleum Institute, the National Automobile Chamber of Commerce, the Society of Automotive Engineers and the United States Bureau of Standards. This motor is known as the A.S.T.M.–C.F.R. Motor, and the method of testing with it which has been tentatively standardized by the A.S.T.M. (Designation D357–34T) is known as the A.S.T.M.–C.F.R. Motor Method, and it differs slightly from the A.S.T.M.–C.F.R. Research Method which preceded it. The motor drives an electrical generator so regulated as to place a constant load on the motor and keep it operating at a constant speed of 900 r.p.m. The water in the cylinderhead jacket is allowed to boil constantly so as to maintain the head at a constant temperature and the air-fuel mixture is fed at a constant temperature of 300° F. The motor is equipped with a variable-compression head, but the compression ratio is not used as a basis for comparison of fuels.

The motor is equipped with a bouncing pin, which, in conjunction with a "knockmeter" indicates the knock intensity, and this intensity is used as the basis for comparison. The compression ratio is first set so that the fuel under test gives a knock intensity such as to show a reading about the middle of the knockmeter scale, and this ratio is then kept constant throughout the test. Various mixtures of the standard reference fuels are then tried in the motor until two mixtures are found, one of which shows a knockmeter reading slightly higher and the other slightly lower than that of the fuel under test. The octane number of the fuel is then calculated by interpolation on the basis of knockmeter readings between the octane numbers of the two mixtures of standard reference fuels. Each knockmeter reading is taken after adjusting the air-fuel mixture supplied by the carburetor to give maximum knock intensity.

Since the latter and other adjustments are not made in operating an automobile on the road, it is obvious that in this method of testing the gasoline is not burned under exactly the same conditions as those obtaining in ordinary automobile operation. Accordingly, it might be expected that the knock rating obtained in the test may not be in perfect agreement with the behavior of the gasoline in service. Several attempts have been made to correlate the laboratory knock ratings with the ratings obtained by road tests. The most extensive work in this line has been done by a committee of the American Petroleum Institute. The results of the work[10] have shown some discrepancies which have resulted in modifications of the testing method and will probably result in still further modifications in the future. The correlation on the whole, however, is very good, and the present method of determining and expressing the detonation characteristics of gasolines will probably remain substantially unchanged until changes in automobile engine design or in characteristics of available fuels necessitate changes.

While the motoring public is generally very much interested in obtaining gasoline of high anti-knock quality, the average motorist knows little if anything about the factors involved in the question

[10]T. A. Boyd, Proc. A.P.I., June 1932, p. 98. Veal, Best, Campbell and Holaday, Proc. A.P.I., Dec. 1932, p. 139. C. B. Veal, Proc. A.P.I., May 1935, p. 165.

of anti-knock fuels. A brief discussion of these factors may be in place here.

The underlying factor is that of efficiency of the engine, that is, the extent to which the energy content of the fuel is converted into useful work. Only the uninformed man is strongly impressed by the statement that one gallon of a gasoline will lift a giant ocean liner several feet out of the water, because the informed man knows that such a statement is based upon calculations assuming that one hundred per cent of the energy content of the gallon of gasoline goes into the work. First of all it must be realized that at most only a fraction—about one-fourth—of the total heat of combustion of a fuel is obtainable as mechanical energy, which fraction is theoretically determined by the temperature of combustion and the drop of temperature during expansion of the gases in the cylinder But even this theoretical fraction of mechanical energy is never completely obtained. Much mechanical energy must be used in overcoming the friction of the machinery necessary to transmit the energy, and only a fraction of the total mechanical energy obtainable from gasoline is useful in raising the load. The total heat energy contents of different gasolines vary only slightly, but the efficiency of the engine in which a gasoline is burned and the mechanism by which the motion of the engine is transmitted to the wheels varies widely and is infinitely more important in determining the economy of the gasoline than is its total heat energy content.

A number of factors influence engine efficiency. One of these is the compression ratio, or extent to which the mixture of gasoline vapor and air is compressed in the cylinder before being exploded. Up to a certain point, the greater the compression ratio, the higher the efficiency of the engine. As compression ratio is increased, however, there is tendency for detonation, or knocking, to set in. This results from the fact that the travel of ignition through the compressed mixture becomes so rapid that the maximum pressure is exerted before the piston reaches the top "dead center." This produces the characteristic knocking sound, results in loss of power, and, if allowed to continue for long periods of time, causes damage to the valves and other parts of the engine.

Automobile manufacturers were for many years limited to a compression ratio of about 5:1 in the design of their engines, due

to the fact that fuels available for use would knock if higher compression ratios were employed. The use of these low compressions resulted in low efficiencies of the engines, and even when so designed knocking was frequently in evidence, particularly in engines in which carbon deposits had been allowed to form. It was to overcome this "carbon knock" that "anti-knock" gasolines were first developed. It was discovered that the addition of small amounts of certain compounds to gasoline served to reduce the tendency to knock. The only one of these anti-knock compounds which has attained commercial importance is tetraethyl lead, which is very commonly used today. It was also found that cracked gasolines, if properly refined, were capable of being produced so as to possess high anti-knock properties. The rapid development of the cracking art has made it possible to offer on the market ever increasing quantities of high anti-knock gasoline.

The availability of anti-knock gasolines made it possible for automobile engine designers to employ higher compression ratios and thus obtain higher efficiencies. Table I[11] shows the changes which

TABLE I

COMPRESSION RATIOS OF VARIOUS CAR MODELS

Car Make	1925	1928	1929	1930	1931	1932	1933	1934	1935
Buick	4.30	4.30	4.30	4.36	4.63	5.03	5.25	5.25	5.25
Cadillac	5.10	4.90	5.30	5.15	5.35	5.33	5.40	6.25	6.25
Chevrolet	4.00	4.50	5.02	5.02	5.00	5.20	5.40	5.45	5.45
Chrysler	4.70	6.00	5.00	5.00	5.00	5.00	6.50	6.50	6.50
Dodge	4.00	5.06	5.18	5.18	5.20	5.35	5.50	6.50	6.50
Ford	3.90	----	4.22	4.22	4.22	4.22	6.30	6.30	6.30
Graham	4.30	5.15	5.51	5.20	5.45	6.50	6.50	6.72	6.70
Oldsmobile	4.70	5.00	5.20	5.20	5.06	5.90	5.50	5.70	6.00
Packard	4.50	4.80	6.00	6.00	6.00	6.00	6.00	6.00	6.50
Plymouth	----	----	4.60	4.60	4.90	4.90	5.50	6.50	6.70
Pontiac	----	4.90	4.90	4.90	4.90	5.40	5.70	6.20	7.10
Studebaker	4.50	4.50	4.30	4.80	5.20	5.20	5.20	6.30	6.30
Terraplane	----	----	----	----	----	----	----	6.30	6.00
Average	4.40	4.95	4.96	4.97	5.08	5.33	5.72	6.18	6.27

have taken place in the compression ratios employed in several popular makes of automobiles. The averages from this table are shown graphically in Fig. 4. Sibley[12] shows, in Fig. 5, the trends in the period 1927–1932 of compression ratios in various types of

[11]Compiled from various Annual editions of "Motor."

[12]B. E. Sibley, Nat. Petr. News, *24*, No. 16, 31 (1932).

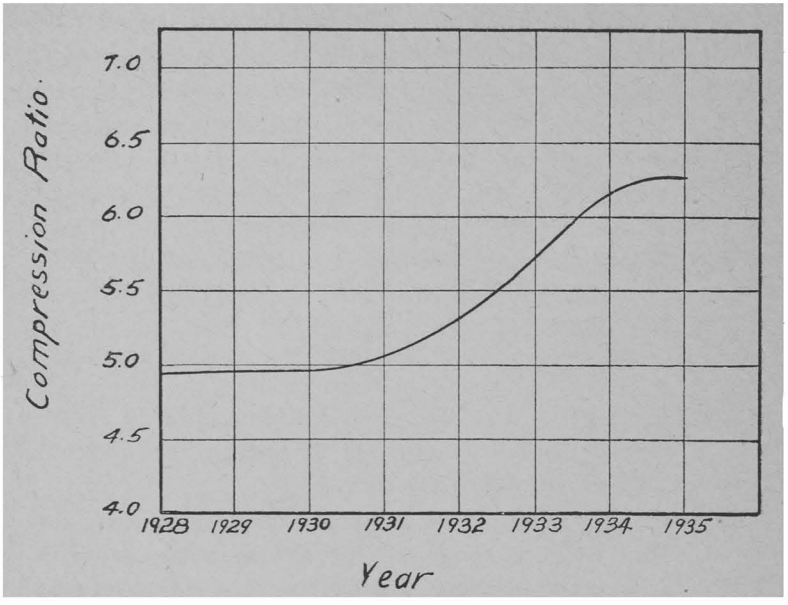

Fig. 4. Average compression ratios of popular makes of automobiles from 1928 to 1935.

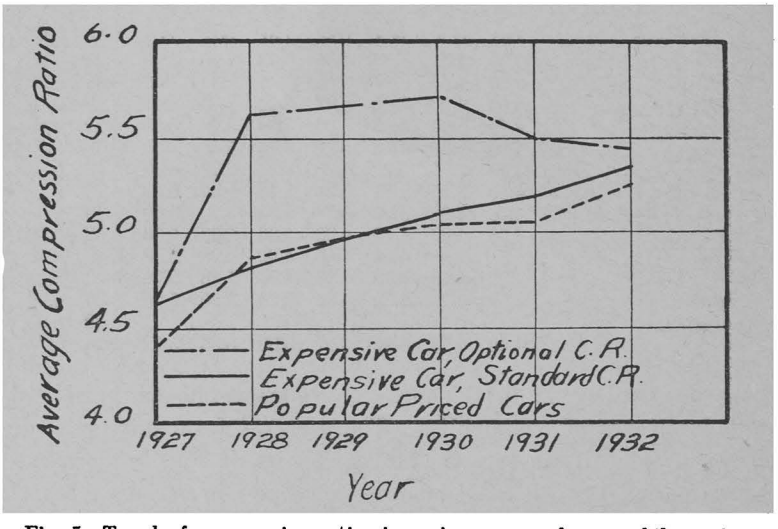

Fig. 5. Trend of compression ratios in various types of automobile engines, 1927–1932 (Sibley, Nat. Petr. News, *24*, No. 16, 31 (1932)).

automobile engines. The uppermost curve in this figure represents the compression ratios obtainable by optional high-compression heads which were offered by some of the more high priced cars during that period. It will be noted that this optional compression ratio tends to approach the standard compression ratios toward the end of this period. The use of such optional high-compression head is not so general today as it was in the period in question. From all these data it is evident that compression ratios have increased considerably in the last eight years, but that this increase has been noticeably arrested in the last year. It appears that next year's average compression ratio will show little if any increase. While theoretically still greater increases in efficiency could be attained by further increased compression ratios, other factors offset this advantage and it is probable that the peak of compression ratio has been reached.

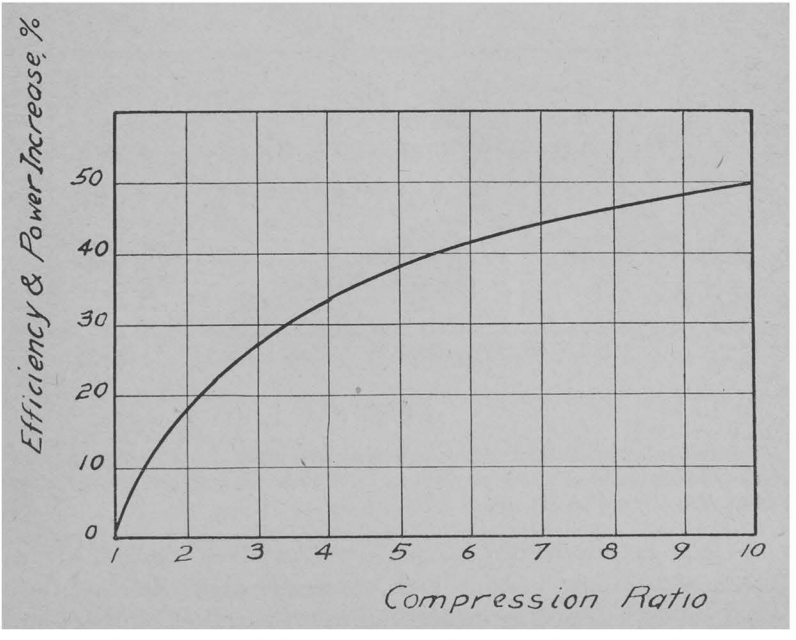

Fig. 6. Theoretical variation of engine efficiency with compression ratio (Sibley, Nat. Petr. News, *24*, No. 16, 31 (1932)).

Sibley *(loc. sit.)* shows, in Figure 6, the increased power and efficiency obtainable by increasing compression ratio, from theoretical considerations. In Figure 7 are shown the same author's data as to changes during the period 1927–1932, in total power, compression ratio, and changes in power due to changes in compression ratio. From this it appears that since 1928 compression ratio increases have not resulted in any significant increases in power. This does not mean that these increases have been without other benefits, such as in efficiency.

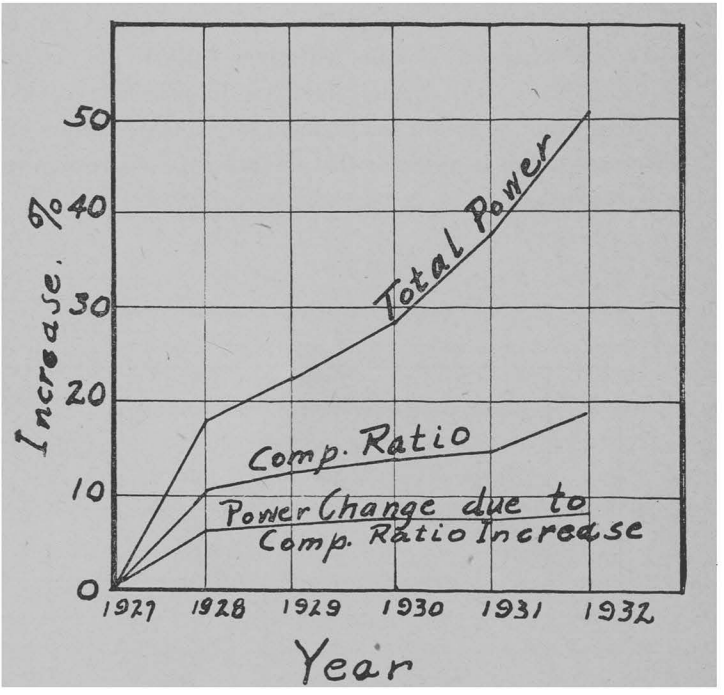

Fig. 7. Changes in total power and compression ratio, and change in power due to changes in compression ratio in automobile engines, 1927–1932 (Sibley, Nat. Petr. News, *24*, No. 16, 31 (1932)).

While the availability of anti-knock gasolines made increased compression ratios possible, these changes in engine design in turn spurred the oil refining industry on to producing gasolines of still higher anti-knock value. This resulted in the so-called race for high octanes which was so evident for several years. Each refiner

endeavored to produce a gasoline of higher octane number, and thereby to gain an advantage in the market. Advertising matter acquainted the public with the subject and taught the motorist to demand gasoline of high octane number. This race has been somewhat slowed down in the past year or two, and it is not improbable that octane numbers will become standardized at about their present level.[13] It remains to acquaint the public with the facts involved and to teach the motorist enough to enable him to decide what gasoline he needs to buy.

It would appear that a chart or table might be prepared in which the proper octane number would be specified for any compression ratio. However, many other factors complicate the matter, so that such a direct relationship does not exist. The material of which the pistons and cylinder head are made exerts a strong influence. An engine having aluminum pistons will operate satisfactorily on a gasoline of lower octane number than would be required for one having cast iron pistons. The design of the head also is important. Engine designers have learned how to shape the combustion space in the cylinder head so as to reduce "hot spots" and other causes of detonation, so that the modern car in which this design feature is employed may employ a higher compression ratio than could one of the older cars and still use the same gasoline satisfactorily. Other factors such as ignition timing, valve timing, manifold cooling, etc., have significant effects on the detonation tendency.

It is practically necessary, with our present knowledge of detonation characteristics, to determine for each individual engine what octane number will give the best results. Henley[14] measured the power output of various cars on gasolines of varying octane number. Figure 8 shows that he found a 1928 Studebaker to give maximum

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[13]One of the factors which has interfered with further increases in compression ratio is the economic difficulty in the production of gasoline of sufficiently high anti-knock quality. Since the above words were written, the announcements of the successful commercial operation of several processes for the polymerization of gaseous hydrocarbons into gasoline of exceptionally high anti-knock value have given rise to some speculation as to the effect of these processes on the future trend of engine design. One technical journal (Refiner *14*, 455 (1935)) in its editorial columns ventures the prophecy that the day of 100 Octane Number gasoline is not far off.

[14]W. V. Henley, Nat. Petr. News, *24*, No. 38, 27–28; 30–32 (1932).

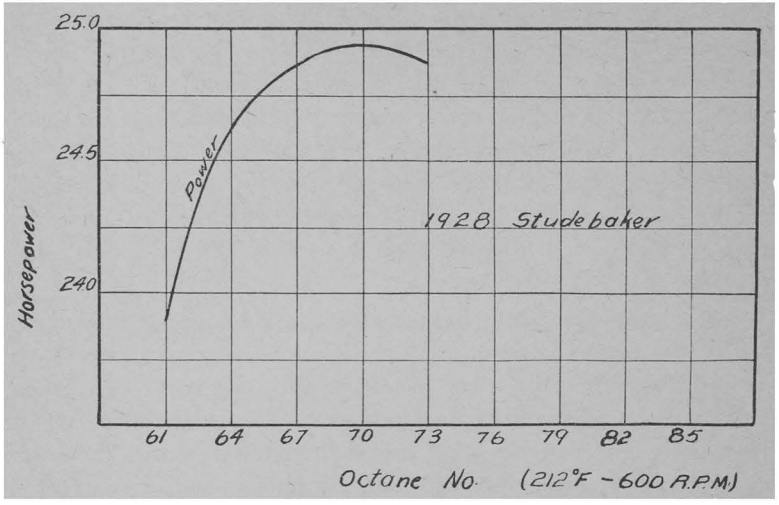

Fig. 8. Variation of power output with octane number of fuel in a 1928 Studebaker engine, under controlled constant conditions (Henley, Nat. Petr. News, *24*, No. 38, 27 (1932)).

power on a gasoline of 70 octane number. Figures 9 and 10 show that, respectively, a 1931 Ford gave maximum power at 73 octane number and a DeSoto motor required 82 octane number for

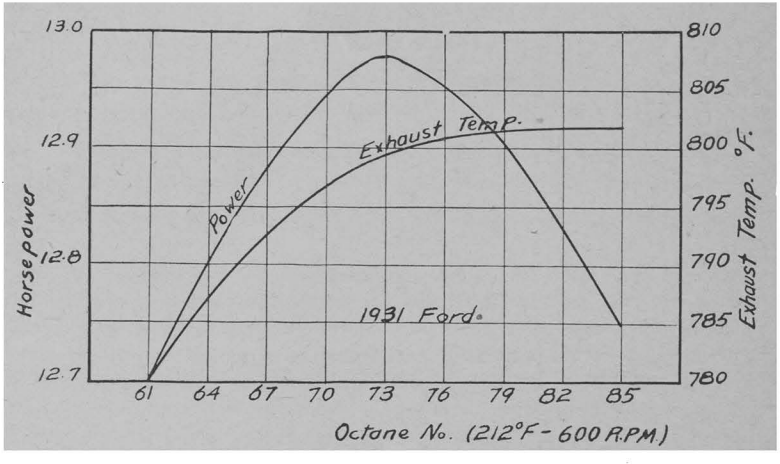

Fig. 9. Variation of power output and exhaust temperature with octane number of fuel in a 1931 Ford engine under constant controlled conditions (Henley, Nat. Petr. News, *24*, No. 38, 27 (1932)).

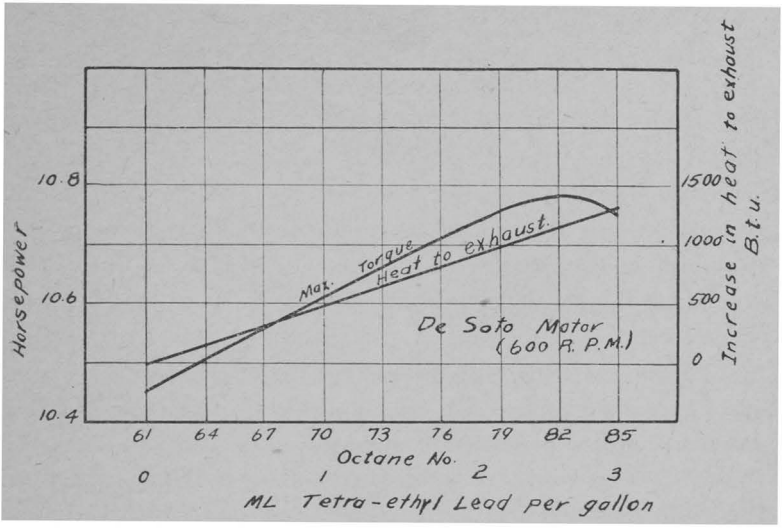

Fig. 10. Variation of torque (power or strength) and heat to exhaust with octane number of fuel in a De Soto engine at constant controlled conditions (Henley, Nat. Petr. News, *24*, No. 38, 27 (1932)).

maximum power. In all cases, the power output drops off sharply when gasoline of higher octane number is used. This brings out a point often overlooked, namely, that the use of a gasoline having too high an octane number can be just as undesirable as the use of one having too low an octane number. This is because a gasoline of high anti-knock value is merely a slow burning gasoline, and if it burns too slowly combustion is not complete within the cylinder. Useful heat will be carried out the exhaust, and part of the charge may even burn in the exhaust valves and manifold, resulting in injury to the valves.

Some gasolines deteriorate in anti-knock value on storage. Hence the knock rating may not be of value unless it is recently determined. Loss of anti-knock value, however, is usually accompanied by other changes, particularly loss of volatility and gum formation, and hence may be detected by detection of these changes.

GUM

Gum in gasoline is a resinous substance which remains as a residue on evaporation. It is particularly objectionable because of its tendency to deposit on the valves and in the feed lines of the

motor. While gum can generally be detected in all gasolines it is not found in objectionable amounts in well refined straight-run gasolines. It is found in considerable amounts in cracked gasolines, particularly those produced by vapor phase cracking. Gum is divided into two types, "preformed" and "potential" gum. Preformed gum is that actually present in the gasoline when tested. Potential gum is the sum of the preformed gum and that which may form in the gasoline on storage. It is only the preformed gum which is objectionable if the gasoline is to be used without long storage.

For many years the only method for the determination of gum was the so-called copper dish test, in which the sample of gasoline was evaporated in a weighed copper dish heated on a steam bath. The increase in weight of the dish was taken as the gum content. The value thus obtained is too high, being more nearly that of potential gum than of preformed gum, since the copper of the dish accelerates the formation of gum, and the long duration of heating allows time for much formation of gum through oxidation of unsaturated compounds. A method recently devised and tentatively standardized (A.S.T.M. Designation D 381–34T) attempts to determine only the preformed gum. In this method the sample of gasoline is evaporated rapidly in a stream of preheated air. The sample is contained in a glass beaker, which is inactive chemically and hence free from the objectionable characteristics of the copper dish, and the expectation is that in the short time required for the evaporation no substantial amount of gum will be formed.

The amount of potential gum is of interest as determining the undesirable changes which will occur when a gasoline is stored. Due to the catalytic effect of the copper, the copper dish gum is not formed under conditions comparable to those obtaining in storage, and even if the amount of such gum were truly representative of the potential gum, there would still be no data as to length of time required for gum formation. Since gum formation appears to result largely from oxidation of certain constituents of the gasoline, various investigators have devised methods of accelerating this process by heating the gasoline under definite oxygen pressure. In

the method described by Voorhees and Eisinger[15] the gasoline sample is placed in a flask which has first been filled with oxygen at atmospheric pressure. The flask is then tightly stoppered and heated in a steam bath, with constant shaking. A mercury manometer connected to the flask indicates the pressure within and serves as an indication of the absorption of oxygen by the gasoline. Winning and Thomas[16] describe an apparatus employing a stainless steel bomb into which a test tube containing the sample is slipped. The bomb is then closed and oxygen admitted under a pressure of 100 pounds per square inch. The bomb is then heated in a steam bath and the pressure resulting is measured on a recording gage. Under conditions such as obtained in such procedures the oxygen pressure first rises corresponding to the increase in temperature from that at which the oxygen is introduced to that of the steam bath, and then drops as oxygen is absorbed by the gasoline. It is always found that a period of time elapses between the attainment of maximum pressure and the initiation of a significant pressure drop. This period is called the "induction period" and is taken as an indication of the stability of the gasoline on storage. As yet no direct relationship between the induction period and the allowable storage period has been shown, but an induction period of as much as three hours is generally taken to indicate a gasoline of sufficient stability to permit of being stored. After such a test has been run, the sample is removed and the amount of gum in it determined. The difference in this amount and that found in the original sample gives the amount formed by oxidation.

It has been found that the addition of small amounts of certain substances to gasolines will increase the stability of these gasolines to gum formation, loss of anti-knock value and color changes. These substances are known as "inhibitors" and a number of such inhibitors are now on the market. The use of inhibitors permits the use of gasolines which otherwise would require costly additional refining. Cracked gasolines frequently have very low stability toward gum formation. They can be treated with sulfuric acid and the gum-forming constituents removed, but such treatment

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[15]Voorhees and Eisinger, A.P.I. Bull. *10*, 169 (1929); S.A.E. Journal, *24*, 584 (1929).

[16]Winning and Thomas, Ind. and Eng. Chem., *25*, 511 (1933).

entails a large loss of gasoline and a substantial reduction in the anti-knock value of the resulting product. By the use of inhibitors satisfactory gasolines can be made without these losses.

GRAVITY

Gravity was long included in all gasoline specifications and is still included in some. The significance of this property is small. It shows the average volatility of the gasoline but does not show any of the other properties determined by the Engler distillation. It shows the weight of the gasoline in pounds per gallon and since the heat content is generally proportional to the weight it gives an index to the heat content, but the connection between this and the "miles per gallon" is negligible. It has been frequently remarked that gasolines of lower A.P.I. gravity have higher anti-knock value, but it should be remembered that this applies only to gasolines of identical boiling range, and hence is not of general validity.

CORROSION AND SULFUR

The copper strip corrosion test reveals any corrosive compounds such as dissolved sulfur or hydrogen sulfide present in the fuel. This test, however, is purely qualitative and is entirely independent from the determination of total sulfur. The "doctor test" is a method of detecting hydrogen sulfide or mercaptans. These substances are the sources of unpleasant odors in gasoline, and the test hence is an indication of "sweetness." It is not an indication of corrosiveness since it does not detect dissolved sulfur or other types of sulfur compounds which may be present.

Determination of total sulfur is very significant. All United States Government specifications limit the sulfur content to 0.1 per cent. It has been found that gasolines containing more sulfur than this may tend to cause corrosion in the bearings, wrist pins, etc. While the harmful action of sulfur differs greatly with different conditions of use, and under some conditions greater amounts can be tolerated than under others, it is generally conceded that the 0.1 per cent specification is a safe limit.

COLOR AND ODOR

Color and odor are sometime considered as important properties of gasoline. The constituents responsible for unpleasant odor are

detected by the doctor test and hence no further specification is necessary. Color in itself has nothing to do with the value of a gasoline, but the public is prejudiced against gasolines having the yellow or brownish cast sometimes found. In former years when straight-run gasolines were commonly sold it is probable that this prejudice was unjustified and that the industry was forced to go to much needless expense and trouble in treating gasoline to produce a water white product. However, in the case of cracked gasolines which are now almost invariably blended with straight-run gasolines, the presence of color is generally an indication of polymerization products which are potent causes of gum formation. However, since undesirable constituents are detected in the test for gum, and since most competitive grade gasolines are artificially colored, any color specification would appear to be superfluous.

SUMMARY OF SPECIFICATIONS

Just how, then, can a motorist know what kind of gasoline to demand and how can he know he is getting what he demands? It is clear that he must demand the proper volatility characteristics as governed by the season and the climate. He must obtain a gasoline free from more than traces of gum and low in sulfur. His requirements with regard to octane number are not so definite. Henley's data, above quoted, are limited in scope and not obtained under actual conditions of operation, and probably indicate octane requirements higher than would be met in ordinary automobile operation. Claydon[17] expressed the opinion that, in cars which were modern at the time he wrote (1932), gasolines having octane numbers of 65 and above would operate satisfactorily. A more recent expression by a British observer[18] may well be quoted. "Although compression ratios in the United States of America now range around 6.2:1 to 6.7:1, a 70 octane number fuel is said to be generally satisfactory. Compression ratios in Great Britain are not so high, ranging from 5.8:1 to 6.2:1 on the average."

Hawley and Bartholomew[19] studied the problem very thoroughly with reference to all the variables influencing the octane number

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[17]A. L. Claydon, Nat. Petr. News, *28*, No. 17, 38 (1932).

[18]L. G. Callingham, Jour. Inst. Petr. Tech., *21*, 464 (1935).

[19]C. D. Hawley and Earl Bartholomew, Proc. A.P.I., *15M* (III), 55 (1934).

requirement. Their findings emphasize the impossibility of any definite connection between the compression ratio and octane requirement. Changes in other operating variables may be made which will permit the operation of an engine on fuels with a considerable range of octane numbers. "However," they say, "over-rich mixtures, low volumetric efficiency and excessively retarded ignition timing are poor substitutes for anti-knock value in the fuel." It is clear, however, that the refiners cannot provide the market with such a variety of fuels that each individual motor may be supplied with the gasoline which exactly satisfies its octane requirement. Each motor must be susceptible to some adjustment to permit its being operated on the most nearly satisfactory fuel available. The "octane selector" provided on some cars is merely a control of ignition timing or spark advance and is probably the most convenient adjustment for this purpose, but should be used only over a narrow range.

The varying demands of the motoring public have led most gasoline producers to offer three grades of fuel on the market, designated as premium grade, regular or competitive grade, and third grade. The most significant, often the only difference between these grades is in the octane number. While the octane numbers of the three grades have not been very well standardized, the samples examined in this survery were found to have the following average octane numbers:

Premimum Grade	75.5
Regular Grade	67
Third Grade	55

Third grade gasoline is generally satisfactory for use in older cars of low compression ratio, certainly for all cars whose compression ratios are 5:1 or lower. Premium grade gasoline is probably necessary in cars having compression ratios higher than the average, though exceptions might be found in cars using aluminum pistons and cylinder heads. For cars lying between the two extremes the regular or competitive grade is generally satisfactory, but individual preference may make one of the other grades

desirable. Vaile, Nordstrom and Brewer[20] conclude that, "the choice of grades depends upon the squeamishness of the individual motorist." A slight sluggishness or a slight knock caused by the use of a third grade gasoline might be tolerated by one motorist in view of the saving in cost. Where rapid pick-up or much heavy pulling or hill climbing are necessary a motorist might prefer to pay the additional cost of the premium grade fuel.

A common misconception among some motorists is that the use of a premium grade gasoline will serve to remove excess carbon deposited in the motor. The use of such gasoline will serve to reduce the knock caused by such carbon, but will not remove it. When such a deposit has formed it should be removed in the usual manner. There is also a prevalent opinion that the use of third grade gasoline will cause carbon to form. Third grade gasoline, if low in gum content and used in a motor to which it is adapted (a low compression motor), will not deposit any more carbon than any other gasoline.

The motorist, then, may know just what kind of a gasoline he needs but still not know whether he is getting it from his filling station. This survey was conducted with the purpose of obtaining information on this point. The number of samples taken unfortunately was not sufficient to permit a representative subdivision of sources such as employed by Vaile, Nordstrom and Brewer[21] in a similar survey conducted in Minneapolis and St. Paul. These authors divided their samples as obtained from:

(1) Sectional and national chains,
(2) Local multi-units,
(3) Bulk filling stations, and
(4) Wholesalers, this group supplying the gasoline sold by the so-called independent dealers.

In Texas conditions do not permit of such a classification as this, gasoline dealers being more nearly divisible into two classes:

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[20]Roland S. Vaile, Alvin L. Nordstrom and Ralph E. Brewer, "Gasoline Distribution in the Twin Cities," The University of Minnesota Press, No. 6, 1933.

[21]*Loc cit.*, p. 11.

(1) Stations owned and operated by large refining and distributing companies, or privately owned and operating as the agents of such companies, and,

(2) Stations privately owned, obtaining their gasolines from wholesalers, these wholesalers in turn obtaining their gasolines in a more or less open market. A few wholesalers operate chains of retail stations, but there is no sharp line of demarcation between such stations and privately owned ones.

The results of this work show that samples taken from stations in class (1) are generally satisfactory. That is, the volatility, gum and sulfur characteristics are within the limits generally specified, the gasolines are non-corrosive and sweet, and the octane ratings conform closely to the averages found for the particular grades of fuels. Among those samples obtained from stations of class (2) a few unsatisfactory gasolines were found. These unsatisfactory samples consisted of several third grade gasolines showing positive corrosion and doctor tests, and one regular grade having an inordinately low octance number and high distillation range. It would be unfair to the stations of class (2) to fail to state that most of the samples obtained from these stations were thoroughly satisfactory.

How the motorist is to know which stations of this class he can depend upon is a difficult question under present conditions. It is to be hoped that some legal restrictions may be placed on the industry which will require a dealer to display a truthful statement of the quality of the gasoline he offers for sale. In the absence of such restrictions, the public would do well to beware of gasolines offered at inordinately low prices. In Austin, any gasoline sold as a regular grade gasoline at 14 cents per gallon or lower, tax paid, is not to be relied upon. Cheaper gasolines may be possible if they are sold as third grade, but 12 cents should probably be the lower limit for these. In localities adjacent to large refining centers slightly lower prices are possible, but in most parts of the State the lower limits should probably be 15 cents for regular and 13 cents for third grade gasoline. "Gasoline wars" are sometimes responsible for prices being cut below actual cost for short periods. However, these conditions result from manifestly unfair tactics, and the thoughtful motorist would do well to refrain from patronizing dealers engaging in such tactics.

PART TWO—EXAMINATION OF GASOLINE SAMPLES

A survey of motor gasolines sold in three Texas cities was conducted in the spring of 1935 by the Bureau of Industrial Chemistry of The University of Texas. The seventy-seven gasolines tested were obtained from San Antonio, Houston and Austin during the last week in February and during March. It is likely that the samples sold in these cities are representative of the gasolines sold in the State.

METHOD OF SAMPLING

Samples were collected in bottles of 2.5 liters capacity, fitted with ground glass stoppers. As a further protection against leakage, a close fitting rubber cap was placed over the mouth of the bottle.

The samples were obtained from the gasoline pumps at service stations in San Antonio and Houston. At Austin the samples were obtained from the distributing stations, distributors donating the samples. The gasoline was flowed into the bottle by holding the end of the hose low in the funnel and filling the bottle with a minimum of disturbance. Then the bottle was quickly stoppered, labeled, sealed and stored in a cool place until ready for testing. Samples secured at points away from Austin were placed in a box with a cork base and supports to hold the tops of the bottles steady.

REID VAPOR PRESSURE

The Reid vapor pressure was the first test made on each sample. The apparatus and procedure for making the test are described in Method D 323–32T of the American Society for Testing Materials. The results of this test are given in Tables IV, VI, and VIII. It will be seen that only one gasoline failed to pass the Federal specifications for United States Motor Gasoline which limits the Reid vapor pressure to 10 pounds per square inch. One other gasoline showed a vapor pressure of exactly 10 pounds, and five showed vapor pressures of between 9.5 and 10 pounds. The ranges of vapor pressures found for the samples examined are indicated in Table II.

TABLE II

REID VAPOR PRESSURE

Reid Vapor Pressure:	All Grades Per Cent	Premium Grade Per Cent	Competitive Grade Per Cent	Third Grade Per Cent
8 Pounds or less	59.8	55.6	38.5	73.8
8.1 to 10 pounds	39.0	44.4	57.7	26.2
Over 10 pounds	1.2	0	3.8	0

OCTANE RATING

The procedure followed in the determination of octane number is that described in Method D 357–34T of the American Society for Testing Materials. The results of the determinations made in this survey are shown in Tables IV, VI and VIII. The average octane number found for premium grade gasolines was 75.5, for competitive or regular grade, 67, and for third grade, 55. It is noteworthy that among the samples obtained from San Antonio there were several having extraordinarily low octane numbers. One sample sold as a competitive grade gasoline, and advertised for antiknock value, had an octane number of 46—much lower than the average third grade gasoline. This particular sample also is characterized by a high distillation range.

DISTILLATION

The A.S.T.M. distillation is an outgrowth of the old Engler distillation, by which name the method is still very commonly described. The standardized procedure is given in Method D 86–30 of the American Society for Testing Materials. Complete results of the distillation are shown in Tables V, VII and IX. Tables IV, VI and VIII also show the corrected 10 per cent, 50 per cent and 90 per cent points. These are the points for which limits are prescribed by the United States Government specifications. The correction here referred to involves assuming that the per cent lost (or unrecovered) was distilled off before the first 10 per cent recovered. This makes the temperatures corresponding to each point on the curve somewhat lower than shown in the distillation data.

Of the gasolines tested, no premium grade fuel failed to pass the Federal specifications, one competitive grade gasoline failed, and three third grade gasolines failed. Two of these third grade gasolines were found in Austin, the other third grade and the one

competitive grade gasoline were found in San Antonio. All four samples failing failed to pass the 10 per cent requirement.

CORROSION TESTS

The copper strip corrosion test is described in Method 530.23 of the Federal Specifications Board and in Method D 130–30 of the American Society for Testing Materials. The test involves immersing a polished copper strip in the sample and holding the sample at a temperature of 122° F. for three hours. Two samples of third grade fuels failed to pass this test.

Another corrosion test described as Method 530.31 of the Federal Specifications Board is identical with this except for the temperature, which is held at 212° F. for three hours. This test is much more severe and is not included as a requirement in any Government specifications. As shown in Tables IV, VI and VIII, three premium grade fuels showed corrosion when subjected to this test. Five competitive grade fuels showed distinct corrosion and three showed a slight corrosion on the copper strip. Ten third grade fuels showed corrosion, including the two which showed corrosion at 122° F. Since this test is very severe and since it is not required in specifications, no comparisons will be recorded, as they may lead to erroneous conclusions.

DOCTOR TEST

The procedure used in making the doctor test is given in Method 521.31 of the Federal Specifications Board. No premium or competitive grade gasoline failed to pass this test. Two third grade fuels gave positive tests, i.e., were found to be "sour." These were the same two fuels which showed corrosion on the copper strip at 122° F.

SULFUR CONTENT

Sulfur was determined by the "lamp method" as described in Method D 90–34T of the American Society for Testing Materials. The results of the determinations made on the individual samples are given in Tables IV, VI and VIII. The average sulfur content of the premium grade gasolines was found to be 0.027 per cent, of the competitive grades, 0.028 per cent, and of the third grades, 0.023 per cent. The average for all grades was 0.025 per cent.

Table III indicates the way in which the sulfur content was found to be distributed in the various grades.

TABLE III

Sulfur Content:	All Grades Per Cent	Premium Grade Per Cent	Competitive Grade Per Cent	Third Grade Per Cent
0.03 per cent or less	65.0	66.7	57.7	69.0
0.031 to 0.060 per cent	20.8	22.2	30.8	14.3
0.061 per cent and up	14.2	11.1	11.5	16.7

Only three samples showed a sulfur content in excess of 0.10 per cent, the maximum allowed by the United States Government specifications. All three were samples of third grade fuels obtained in San Antonio. It is interesting to note that none of these gave positive corrosion or doctor tests, though one of them did show corrosion at 212° F.

GUM

The apparatus and procedure for the gum determination are described in Method D 381–34T of the American Society for Testing Materials. The data on gum determinations are given in Tables IV, VI and VIII. It may be seen that the gum content of the samples was small. Only three samples seemed to have an excessive amount. In two of these samples there was present an oil which would not evaporate at the temperature of the test. Hence, this weight is not entirely due to gum but partly to the oil in these instances. The oil might have been added in order to produce a so-called "lubricated gasoline" or it might have been added as a solvent for the dye with which the gasoline was colored. The one sample which showed a high gum content, without the presence of the non-volatile oil, contained 17.2 milligrams of gum per 100 cubic centimeters. It is generally considered that a gasoline containing less than 15 milligrams will not cause trouble.

GRAVITY DETERMINATION

The gravity determinations were made with a hydrometer at room temperatures, and the values observed converted to 60° F. by means of the standard conversion tables, as given in the Cross Handbook. Average gravities observed were as follows:

	A.P.I. Deg.
Premium grade	61.9
Competitive grade	61.3
Third grade	59.7

UNSATURATES

A determination of the loss on treatment with sulfuric acid was made as an approximate determination of the amounts of unsaturated hydrocarbons present, and hence an index to the extent of cracking to which the gasolines had been subjected. The procedure followed was: In a special Babcock flask, 10 cubic centimeters of the sample were mixed with 20 cubic centimeters of concentrated sulfuric acid, and shaken gently for five minutes. More acid was then added to bring the upper liquid level to the uppermost graduation in the neck of the flask. The flask was allowed to stand over night and the volume of the gasoline remaining in the neck of the flask was then read. The loss in volume from the original 10 cubic centimeters was taken as the amount of unsaturates. The results showed the following average amounts of unsaturates:

	Per Cent
Premium grade	8.2
Competitive grade	14.7
Third grade	9.2

COLOR

Since the amount of color in a gasoline is of no practical value, no attempt at colorimetric determination was made. The presence or absence of artificial color was noted. The use of such coloring has become very general in recent years. It was thought that the dyes used might show up as gum, but this was not found to be the case.

Of the gasolines examined, all the premium grade gasolines were found to be colored, most of them red, with the exception of one which was an aviation gasoline. All but two of the competitive grade gasolines were colored, most of them yellow or amber. No third grade gasolines were found to be colored.

TABLE IV

Premium Grade Motor Fuels

No.	Octane number	Price Cents per Gal.	Gravity Deg. A.P.I.	Reid Vapor Press.	Corrosion 122 Deg.	Corrosion 212 Deg.	Doctor Test.
Samples from Austin, Texas							
1–E	74	20	60.6	6.85	Neg.	Neg.	Neg.
3–E	77	20	64.2	7.60	"	"	"
8–E	76	20	64.4	7.87	"	Pos.	"
9–E	77	20	60.9	8.80	"	Neg.	"
9–V*	77	....	62.1	5.55	"	"	"
10–E	76	20	61.4	8.02	"	"	"
26–E	77	19	66.5	8.65	"	Pos.	"
Av.	76	20	62.9	7.62			
Samples from Houston, Texas							
12–C	71	19	56.4	8.92	Neg.	Neg.	Neg.
13–E	77	19	60.6	6.75	"	Pos.	"

*Aviation gasoline.

TABLE IV—Continued

No.	Unsaturates Per Cent	Gum, mgms/100 c.c.	Sulfur Per Cent	Corrected 10 Per Cent Point Deg. F.	Corrected 50 Per Cent Point Deg. F.	Corrected 90 Per Cent Point Deg. F.
Samples from Austin, Texas						
1–E	4.5	3.4	0.02	140	235	338
3–E	9.5	35.8*	Nil.	137	200	274
8–E	5.5	1.2	0.01	140	213	294
9–E	10.0	0.6	0.08	134	238	349
9–V	2.0	0.6	Nil.	167	209	245
10–E	4.0	1.0	0.04	133	238	339
26–E	5.0	1.0	0.03	127	204	304
Av.	5.6	1.3	0.03	140	220	305
Samples from Houston, Texas						
13–E	16.5	1.8	0.05	132	232	341
12–C	16.5	4.2	0.03	128	239	354

*This sample contained a non-volatile oil which is included in the gum as determined. Not included in average.

TABLE V

Premium Grade Motor Fuels

Engler Distillations

No.	First drop	10 Per Cent	20 Per Cent	30 Per Cent	40 Per Cent	50 Per Cent	60 Per Cent	70 Per Cent	80 Per Cent	90 Per Cent	E.P.	Residue	Recovery	Loss
Gasolines from Austin, Texas														
1–E	101	145	174	197	219	238	260	285	312	345	393	1.0	97.2	1.8
3–E	107	143	160	177	189	202	216	230	249	281	334	2.8	95.5	1.7
8–E	103	145	166	184	201	217	231	247	285	298	362	0.9	97.0	2.1
9–E	97	137	163	189	217	243	267	291	323	355	399	1.1	97.0	1.9
10–E	97	143	174	199	221	243	264	288	316	351	398	1.0	96.5	2.5
26–E	94	134	156	175	192	207	225	247	279	320	370	1.5	96.0	2.5
Av.	100	141	167	187	207	225	244	265	294	325	376	1.4	96.6	2.0
Gasolines from Houston, Texas														
13–E	94	139	167	190	215	237	260	285	317	352	389	1.1	96.8	2.1
12–C	100	132	163	191	219	242	267	297	326	360	397	1.3	97.5	1.2

TABLE VI

COMPETITIVE GRADE MOTOR FUELS

No.	Octane number	Price Cents per Gal.	Gravity Deg. A.P.I.	Reid Vapor Press.	Corrosion 122 Deg.	Corrosion 212 Deg.	Doctor Test.
Samples from Austin, Texas							
1–A	70	18	60.2	7.5	Neg.	Slight	Neg.
3–A	69	18	60.8	7.60	"	"	"
4–A	63	18	60.5	8.7	"	Neg.	"
5–A	69	18	57.3	7.7	"	"	"
6–A	67	18	61.6	8.6	"	"	"
7–A	68	18	63.6	9.5	"	Slight	"
8–A	70	18	63.0	8.9	"	Neg.	"
9–A	71	18	59.2	7.4	"	"	"
10–A	72	18	60.8	8.5	"	Pos.	"
25–A	70	16	65.4	10.0	"	Neg.	"
26–A	70	17	60.7	8.2	"	"	"
Av.	69	18	61.2	8.4			
Samples from Houston, Texas							
11–A	67	17	64.7	9.3	Neg.	Pos.	Neg.
12–A	68	17	57.9	8.7	"	Neg.	"
13–A	70	17	62.7	8.6	"	"	"
15–A	70	17	65.1	10.5	"	"	"
17–A	70	17	61.3	7.4	"	"	"
19–A	66	17	60.5	7.2	"	"	"
24–A	69	17	59.4	7.7	"	"	"
Av.	68.5	17	61.7	8.5			
Samples from San Antonio, Texas							
29–A	70	17	63.9	9.6	Neg.	Neg.	Neg.
33–A	67	18	58.7	8.5	"	"	"
34–A	51	18	60.7	6.3	"	Slight	"
36–A	70	18	58.8	6.8	"	Pos.	"
39–A	46	18	57.1	5.0	"	Neg.	"
43–A	64	18	61.6	8.2	"	"	"
Av.	61.3	18	60.1	7.4			

TABLE VI—Continued

No.	Unsaturates Per Cent	Gum, mgms/100 c.c.	Sulfur Per Cent	Corrected 10 Per Cent Point Deg. F.	Corrected 50 Per Cent Point Deg. F.	Corrected 90 Per Cent Point Deg. F.
Samples from Austin, Texas						
1–A	21.0	2.2	0.03	139	249	348
3–A	20.0	90.0*	Nil.	138	252	346
4–A	19.0	8.0	"	138	243	346
5–A	22.0	0.7	"	144	256	370
6–A	16.0	1.8	0.04	135	245	357
7–A	21.5	2.2	0.07	126	211	304
8–A	17.5	0.2	0.01	134	230	318
9–A	14.0	0.8	0.05	142	252	346
10–A	19.3	1.6	0.03	138	251	344
25–A	7.0	0.6	Nil.	122	195	300
26–A	16.5	3.2	0.03	144	245	342
Av.	17.6	2.1	0.02	136	239	338
Samples from Houston, Texas						
11–A	14.8	2.2	0.07	126	207	304
12–A	21.5	2.0	0.03	139	245	363
13–A	17.5	0.2	0.03	134	238	345
15–A	8.5	0.5	Nil.	122	195	308
17–A	7.0	0.3	"	142	230	336
19–A	12.0	2.8	0.02	144	249	350
24–A	7.5	1.0	0.05	151	245	354
Av.	12.7	1.3	0.03	137	230	336
Samples from San Antonio, Texas						
29–A	11.0	2.0	Nil.	124	207	324
33–A	12.5	3.4	0.04	127	247	377
34–A	6.5	0.8	0.08	140	251	356
36–A	15.0	3.2	0.05	143	257	349
39–A	6.0	2.4	0.02	170	267	377
43–A	20.8	1.7	0.02	137	237	342
Av.	12.0	2.3	0.03	140	244	354

*This sample contained a non-volatile oil which is included in the gum, as determined.

TABLE VII

Competitive Grade Motor Fuels

Engler Distillations

No.	First drop	10 Per Cent	20 Per Cent	30 Per Cent	40 Per Cent	50 Per Cent	60 Per Cent	70 Per Cent	80 Per Cent	90 Per Cent	E.P.	Residue	Recovery	Loss
Gasolines from Austin, Texas														
1-A	102	144	178	208	232	254	276	298	322	352	382	1.0	97.0	2.0
3-A	96	144	168	208	234	258	279	300	327	353	402	1.5	96.0	2.5
4-A	93	140	169	197	223	245	268	290	316	347	397	1.5	98.0	0.5
5-A	106	158	194	225	241	265	304	325	350	383	410	1.4	95.0	3.6
6-A	100	140	169	199	226	251	277	302	335	361	409	1.5	96.5	2.0
7-A	94	131	151	173	194	214	231	251	270	308	365	1.2	97.0	1.8
8-A	101	140	166	188	211	233	254	270	299	329	375	1.0	96.6	2.4
9-A	98	148	180	210	235	258	280	304	328	361	392	1.5	96.0	2.5
10-A	96	143	175	205	232	256	278	304	325	352	381	1.5	96.5	2.0
25-A	96	127	144	161	180	199	217	237	263	308	372	1.0	97.0	2.0
26-A	104	150	180	207	230	250	274	296	320	351	392	1.0	96.5	2.5
45-A	98	136	168	198	226	250	276	307	334	372	410	1.0	96.0	3.0
46-A	97	129	152	173	194	211	232	254	280	320	374	1.2	95.5	3.3
Av.	100	141	169	195	220	242	265	287	313	346	387	1.3	96.4	2.3
Gasolines from Houston, Texas														
11-A	93	131	153	173	194	212	231	250	275	314	374	1.4	96.5	2.1
12-A	107	145	176	206	233	256	282	309	340	371	400	1.3	96.4	2.3
13-A	93	139	166	194	220	245	270	293	323	353	390	0.9	97.0	2.1
15-A	94	128	147	164	182	200	220	242	267	322	387	1.4	96.0	2.6
17-A	100	147	174	197	217	235	249	280	307	345	388	1.1	96.8	2.1
19-A	100	148	178	204	228	252	275	300	324	354	391	1.4	97.0	1.6
24-A	105	154	183	206	228	247	268	284	318	349	388	1.2	97.5	1.2
Av.	99	142	169	192	215	235	256	279	308	345	389	1.2	96.8	2.0
Gasolines from San Antonio, Texas														
29-A	97	130	141	170	192	212	234	257	292	336	390	1.4	96.0	2.6
33-A	95	134	167	198	226	256	288	320	355	388	415	1.3	95.7	3.0
34-A	106	144	182	210	234	255	275	301	329	360	404	1.4	97.0	1.6
36-A	98	148	184	213	240	262	285	307	329	356	380	1.1	96.8	2.1
39-A	118	174	206	229	250	270	296	320	350	382	423	1.0	97.5	1.5
43-A	100	140	169	195	219	242	260	285	314	346	398	1.7	97.0	1.3
Av.	102	145	175	203	227	249	273	298	328	361	402	1.3	96.7	2.0
Aviation Fuel from Austin, Texas														
9-V	120	171	185	195	203	210	219	227	237	247	297	1.0	97.5	1.5

TABLE VIII

Third Grade Motor Fuels

No.	Octane number	Price Cents per Gal.	Gravity Deg. A.P.I.	Reid Vapor Press.	Corrosion 122 Deg.	Corrosion 212 Deg.	Doctor Test.
Samples from Austin, Texas							
1–B	57	15	61.5	8.27	Neg.	Neg.	Neg.
2–B	57	14	60.1	5.30	"	Pos.	"
3–B	63	15	59.4	8.00	"	"	"
4–B	49	15	59.2	7.27	"	Neg.	"
5–B	49	15	58.2	6.10	"	Pos.	"
6–B	55	15	60.4	7.87	"	Neg.	"
7–B	55	15	60.0	7.45	"	"	"
8–B	56	15	62.8	8.90	"	"	"
9–B	63	15	57.7	7.25	"	"	"
10–B	63	15	59.1	7.40	"	"	"
26–B	61	14	58.9	7.75	"	"	"
27–B	54	12	59.1	6.92	"	"	"
28–B	61	15	59.2	5.65	"	"	"
43–B	56	14	60.3	6.98	"	"	"
Av.	57	15	59.8	7.44			
Samples from Houston, Texas							
11–B	56	15	60.5	7.45	Neg.	Pos.	Neg.
12–B	61	15	62.2	8.55	"	Neg.	"
13–B	59	15	63.7	8.50	"	Pos.	"
14–B	55	14	61.0	9.40	Pos.	"	Pos.
15–B	64	14	62.7	9.70	Neg.	Neg.	Neg.
16–B	54	14	60.0	8.45	Pos.	Pos.	Pos.
17–B	64	14	57.6	7.70	Neg.	Neg.	Neg.
18–B	55	13	61.1	9.50	"	"	"
19–B	58	15	61.8	8.10	"	"	"
20–B	64	14	58.2	7.22	"	"	"
21–B	55	14	58.9	6.55	"	"	"
22–B	56	14	60.7	7.95	"	"	"
23–B	57	15	60.8	6.90	"	"	"
24–B	56	14	60.7	8.32	"	"	"
Av.	58	14	60.7	8.16			
Samples from San Antonio, Texas							
29–B	56	15	59.9	6.75	Neg.	Neg.	Neg.
30–B	46	15	57.9	5.60	"	"	"
31–B	47	16	57.8	4.60	"	"	"
32–B	54	15	59.3	8.32	"	"	"
33–B	48	16	61.9	6.30	"	Pos.	"
34–B	49	15	61.1	6.12	"	"	"
35–B	46	15	57.6	4.97	"	Neg.	"
36–B	58	16	58.5	7.05	"	"	"
37–B	47	16	57.3	4.82	"	"	"
38–B	55	15	59.2	7.35	"	"	"
40–B	51	15	58.0	6.42	"	"	"
41–B	45	16	58.0	5.30	"	"	"
42–B	53	16	59.1	6.85	"	"	"
44–B	49		56.5	4.23	"	Pos.	"
Av.	50	15½	58.9	6.19			

TABLE VIII—Continued

No.	Unsaturates Per Cent	Gum, mgms/100 c.c.	Sulfur Per Cent	Corrected 10 Per Cent Point Deg. F.	Corrected 50 Per Cent Point Deg. F.	Corrected 90 Per Cent Point Deg. F.
Samples from San Antonio, Texas						
29-B	16.0	3.4	0.02	144	253	357
30-B	6.5	0.4	0.10	162	274	390
31-B	5.0	Nil.	0.03	168	258	361
32-B	18.5	8.0	0.32	161	256	357
33-B	4.0	Nil.	0.08	137	248	352
34-B	2.5	1.4	0.13	147	245	356
35-B	4.0	1.2	0.16	167	277	386
36-B	16.5	4.4	0.03	152	261	363
37-B	6.0	0.6	0.02	160	265	376
38-B	7.5	1.8	Nil.	144	254	369
40-B	18.0	17.2	0.01	145	259	360
41-B	7.0	1.2	0.05	163	270	382
42-B	8.0	2.0	Nil.	158	255	372
44-B	8.0	0.4	0.04	161	259	371
Av.	9.1	3.0	0.07	155	260	368
Samples from Austin, Texas						
1-B	6.0	1.8	Trace	131	242	358
2-B	19.0	1.2	"	132	261	369
3-B	17.0	3.2	0.01	140	260	364
4-B	5.5	1.4	Nil.	141	259	372
5-B	5.0	1.8	Trace	171	265	352
6-B	14.0	3.8	0.02	140	264	367
7-B	9.0	0.2	0.02	146	254	360
8-B	7.0	0.8	Nil.	148	231	321
9-B	13.0	Nil.	0.05	141	261	370
10-B	17.0	3.8	0.07	135	262	366
26-B	17.5	1.6	0.04	140	262	364
27-B	2.0	Nil.	Nil.	151	246	357
28-B	24.0	1.0	0.04	168	259	353
43-B	16.5	1.4	0.03	148	259	360
Av.	12.4	1.5	0.02	145	256	360
Samples from Houston, Texas						
11-B	5.0	4.4	0.09	157	244	341
12-B	4.0	Nil.	0.02	145	228	314
13-B	13.0	1.4	0.01	136	243	350
14-B	5.5	Nil.	0.02	136	240	372
15-B	14.5	3.4	0.03	136	225	324
16-B	6.0	1.2	Trace	145	246	372
17-B	3.5	Nil.	0.01	145	250	344
18-B	2.0	"	Nil.	135	244	356
19-B	5.5	"	0.01	141	237	335
20-B	5.5	0.2	0.01	143	238	340
21-B	8.5	Nil.	Nil.	155	242	350
22-B	4.0	0.4	"	145	235	347
23-B	5.5	0.8	0.01	137	236	330
24-B	4.0	0.6	Nil.	135	237	350
Av.	6.2	0.9	0.02	143	239	345

TABLE IX

Third Grade Motor Fuels

Engler Distillations

No.	First drop	10 Per Cent	20 Per Cent	30 Per Cent	40 Per Cent	50 Per Cent	60 Per Cent	70 Per Cent	80 Per Cent	90 Per Cent	E.P.	Residue	Recovery	Loss
Gasolines Purchased from Austin, Texas														
1–B	96	135	165	194	220	244	266	292	326	365	426	1.3	97.2	1.5
2–B	98	143	182	210	250	268	298	324	344	379	402	1.5	96.0	2.5
3–B	98	147	180	210	240	263	288	311	331	370	400	1.2	97.0	1.8
4–B	98	150	184	214	240	265	289	310	347	382	419	1.0	96.5	2.5
5–B	109	182	212	232	251	270	288	300	333	361	401	1.3	96.5	2.2
6–B	100	154	186	217	244	270	293	319	345	376	406	0.9	96.3	2.8
7–B	103	155	183	208	233	257	280	305	332	365	410	1.2	97.5	1.3
8–B	101	160	182	201	219	235	251	271	297	337	394	1.3	96.0	2.7
9–B	98	148	181	211	240	265	289	315	342	376	410	1.1	97.0	1.9
10–B	102	142	180	210	240	267	290	315	340	374	413	1.2	97.0	1.8
26–B	96	147	184	217	242	267	291	316	340	372	415	1.0	97.0	2.0
27–B	108	153	182	207	228	248	270	296	329	362	404	0.9	97.8	1.3
28–B	110	170	198	220	240	260	284	304	327	356	397	0.9	98.8	0.8
43–B	103	155	190	217	241	263	284	310	336	367	407	1.6	97.0	1.4
Av.	101	153	185	212	238	260	283	307	333	367	400	1.2	96.9	1.2
Gasolines from Houston, Texas														
11–B	110	159	186	208	228	246	265	288	314	348	401	1.1	97.5	1.4
12–B	99	150	176	197	216	231	247	265	280	320	369	1.0	97.5	1.5
13–B	100	138	163	190	217	245	272	290	323	352	402	1.2	98.0	0.8
14–B	98	140	170	196	220	243	268	298	328	380	430	1.0	97.5	1.5
15–B	100	140	165	186	207	228	245	263	294	330	374	1.0	97.5	1.5
16–B	100	149	177	202	225	248	270	298	334	379	426	1.2	97.5	1.3
17–B	105	150	186	206	229	253	271	296	322	352	421	1.4	97.0	1.6
18–B	96	140	172	198	223	246	270	296	328	360	392	1.5	97.5	1.0
19–B	100	143	170	195	218	238	257	278	304	336	375	1.2	98.0	0.8
20–B	100	143	178	202	224	242	264	287	314	346	394	1.5	97.0	1.5
21–B	103	158	186	198	229	247	267	293	320	357	410	1.2	97.5	1.3
22–B	100	148	177	202	222	241	263	288	320	354	411	0.7	98.0	1.3
23–B	98	140	177	200	220	238	258	279	306	336	378	0.9	97.5	1.6
24–B	103	143	173	199	221	242	264	292	324	361	383	1.2	96.3	2.5
Av.	101	146	175	197	221	242	263	287	315	351	398	1.2	97.6	1.2
Gasolines from San Antonio, Texas														
29–B	98	147	179	208	234	256	282	305	332	363	402	1.1	97.7	1.2
30–B	100	164	201	229	253	278	309	330	360	394	430	1.4	97.5	1.1
31–B	111	170	202	226	245	261	289	312	337	366	410	0.9	98.0	1.1
32–B	99	164	193	221	242	258	281	302	327	365	414	1.4	96.8	1.8
33–B	100	140	182	208	231	252	277	300	326	356	399	1.4	97.5	1.1
34–B	98	152	183	207	226	251	280	305	331	364	408	1.2	97.0	1.8
35–B	98	169	201	233	258	280	303	330	360	391	429	0.9	98.0	1.1
36–B	108	155	183	213	240	264	280	311	339	367	413	1.0	98.0	1.0
37–B	107	167	200	225	245	268	299	321	350	383	425	1.3	97.3	1.4
38–B	104	154	186	213	237	260	283	308	340	378	408	1.3	96.5	2.2
40–B	108	150	183	213	238	263	288	313	337	366	410	1.2	97.2	1.6
41–B	113	167	200	226	250	272	298	328	355	387	425	1.4	97.5	1.1
42–B	103	160	190	214	237	259	282	310	344	378	417	1.2	97.0	1.8
44–B	116	162	199	220	240	260	285	310	340	375	418	0.9	98.3	0.8
Av.	105	158	192	218	241	263	288	313	341	374	415	1.2	97.6	1.2